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Effects of Acid Precipitation on a Typic Quartzipsamment Soil in Florida

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by

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Mounding of water was observed to occur at the water table surface. The effect of the acid treatments from a very large rain event could be observed in the groundwater near the lake within 24 hours.

The effect of acid rain is not long lasting and the soils recover the normal soil leachate chemistry within 48 hours.

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EFFECTS OF ACID PRECIPITATION ON A TYPIC QUARTZIPSAMMENT SOIL IN FLORIDA 1/

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Abstract

The magnitude of leaching of nutrients from the soil surface to the water table and to a nearby drainage system depends on many factors unique to the site. The sensitive deep sands of Florida present an extreme case of low nutrient status and high water flux to great depth. In addition, water table characteristics, both physical and chemical, influence the horizontal flow vis-a-vis the vertical flows. Investigations using artificial acid treated irrigation water (70:30, H_2SO_4:HNO_3) at pH 3.0, 3.7, and a 4.7 control over a two year period at a lake site in north central Florida suggest a relatively high and rapid loss of nutrients from the soil surface to the water table 4 m below under acid irrigation conditions. Considering the low CEC (3.5 me/100g), the low base saturation (4%) and the high hydraulic conductivity (74 cm/hr), the implication of effects in the rooting zone of natural vegetation is clear. The magnitude of leaching also depends on the nature of the ion, the depth being considered and the acid treatment. Readsorption of ions in the soil profile was shown to occur which further complicates the overall assessment of the real effect of acid rain. Most of the applied water, regardless of the amount, is lost from the soil site to the water table after 48 hours. Thus plant nutrients could potentially be rapidly and completely lost from the soil. Lateral movement in the groundwater to the lake likewise is very fast due to the high hydraulic conductivity.

Mounding of water was observed to occur at the water table surface. There was essentially little non-vertical flow to the water table, and horizontal wave movement towards the lake is rapid, despite the essentially flat water table extending more than 50 meters from the lake. The effect of the acid treatments from a very large rain event could be observed in the groundwater near the lake within 24 hours.

Laboratory studies on sealed soil columns under saturated water flow conditions at pH 3.0, 3.7, and 4.7 (70:30, H_2SO_4:HNO_3) show ion movement characteristics very similar to those observed in the field. The effect of acid rain is not long lasting and the soils recover the normal soil leachate chemistry within 48 hours. Calcium was the dominant nutrient in

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the system and showed the greatest magnitude of loss. Magnesium, however, although present at 25% of the Ca, exhibited the greatest percentage loss from the rooting zone. Potassium showed lower but continual loss. Sulfate adsorption was clearly observed. Aluminum showed increased concentration in soil leachates with the more acid treatments.

Introduction

The impact of acid precipitation on terrestrial environments may result in chemical and biological alterations. Chemical alterations may consist of leaching of essential alkaline cations with subsequent eventual decrease in soil fertility and productivity as well as release of heavy metals and aluminum impacting groundwater and surface water environments (Babich et al., 1980; Cronan et al., 1978; Wainwright, 1980b).

The magnitude of leaching of nutrients from the soil surface to the water table and to a nearby drainage system depends on many factors unique to the site. The sensitive deep sands of Florida present an extreme case of low nutrient status and high water flux to great depth. In Florida approximately 35% of the northern half of the state is covered by quartzipsamments. In fact the largest acreage of citrus production in Florida is on this type of soil. Acid precipitation could remove significant quantities of bases and micronutrients from these soils. Investigators have noted the leaching of nutrients from soils treated with acid precipitation (Strayer and Alexander, 1981; Bache, 1980; Wilson, 1980).

Losses of bases from soils used for forest production would be particularly damaging to forest productivity in that basic cations are not applied to forest plantations. Johnson et al. (1980), in an examination of the growth rates on a New Jersey Hapludult and a Quartzipsamment, have suggested that acid precipitation may be having a deleterious effect on tree growth.

The purpose of this investigation was to examine the effects of acid precipitation on the movement of selected elements and on changes in chemical properties of a Typic Quartzipsamment soil in a field study.

Acidic Deposition Effects on Agricultural Crops

Recent research has shown that acid deposition has the potential to affect agricultural crops. Presently, the knowledge of effects is primarily based on experimental studies with plants grown under controlled conditions and on evidence from natural systems (Cowling, 1980b). Direct effects of acid deposition on agricultural crops under natural conditions have not yet been clearly documented; however, experimentation now underway may provide such evidence.

Agricultural crop or vegetation effects may be divided into direct or indirect categories (Cowling, 1980a, 1980b; Tamm and Cowling, 1976).

Direct Effects on Vegetation

As outlined by Newman et al. (1982), the following effects have been hypothesized or documented under experimental conditions:

1. Development of foliar lesions, galls, and necrotic zones (Shriner and Johnston, 1981; Irving, 1978; Evans and Curry, 1979; Evans et al., 1977a, 1977b; Ferenbaugh, 1976; Wood and Bormann, 1974);

2. Accelerated erosion of leaf cuticle and protective coatings (Tamm and Cowling, 1976; Shriner, 1976);

3. Interference with normal functioning of guard cells (Tamm and Cowling, 1976);

4. Poisoning of plant cells after diffusion of acidic substances through stomata or cuticle (Cowling, 1980a);

5. Disturbance of normal metabolism and growth processes such as photosynthesis and respiration (Ferenbaugh, 1976);

6. Alteration of leaf and root exudation processes (Tamm and Cowling, 1976);

7. Interference with reproductive processes such as pollen viability and seed germination (Lee and Weber, 1976);

8. Synergistic interactions with other stress factors such as gaseous pollutants (Irving and Miller, 1978); and

9. Inhibition of bud and seedling growth (Matziris and Nakos, 1977; Lee and Weber, 1976).

Jacobson (1980) has stated that herbaceous plants are more sensitive than deciduous trees, which are more sensitive than conifers. The most sensitive foliar stage is immediately preceding maximum leaf development.

Indirect Effects on Vegetation

According to Newman et al. (1982), indirect effects on vegetation and soil are thought to be capable of inducing significant effects on ecosystem function.

Reported or hypothesized indirect effects include (Newman et al., 1982):

1. Accelerated leaching of substances from foliar organs;

2. Increased susceptibility to environmental stresses such as water;

3. Changes in symbiotic associations including lichens, mycorrhizae, and nitrogen-fixing organisms (Shriner and Johnston, 1980); and

4. Reduced microbial activity and litter decomposition.

Agricultural Crop Effects

Experimental studies with plants grown under controlled (or semicontrolled) conditions have demonstrated that visible foliar symptoms and yield responses can be produced on certain crops (Table 1). The effects

Table 1. Simulated Acid Precipitation Effects on Vegetation or Yields of Selected Agricultural Crops

Crop	pH at Which Effect Occurs: Yield decrease (fresh weight)	pH at Which Effect Occurs: Foliar damage[a]	Source
Bean (red kidney)	none	3.2[b]	Shriner & Johnson 1981
Beet	3.0	3.5	Lee et al. 1980
Broccoli	3.0	3.5	
Cabbage	none	3.0	
Carrot	4.0	3.0	
Cauliflower	none	3.5	
Lettuce	none	3.5	
Lettuce	4.0(2.7)[c]	---	Evans et al. 1982
Mustard greens	4.0	3.5	Lee et al. 1980
Onion	none	none	
Pea	none	3.5	
Pepper	3.5[d]	4.0	
Potato	4.0	3.5	
Radish	3.5	3.5	
Soybean (Amsoy)	4.1	---	Evans et al. 1983
Soybean (Lee)	none	3.2[b]	Shriner & Johnson 1981
Soybean (Williams)	none	---	Evans et al. 1983
Spinach	none	3.5	Lee et al. 1980
Strawberry	4.0[e]	3.0	
Swiss Chard	none	4.0	
Tobacco	---	3.5	
Tomato	3.5[e]	3.5	

a 10% of plants showed leaf injury
b 75% reduction in number of nodules
c pH in parentheses notes when dry weight was affected
d Significant increase in yield at pH 3.5, no significant difference at pH 3.0
e Significant increase in yield at this and lower pH's

of acid rain are variable and at any one pH depend upon plant species, variety, soil and fertility, length of acid rain irrigation, the number of irrigations and whether control rain is applied between the acid rain irrigation events. Shiver and Johnson (1981) used pH 6.0 as the control rain whereas all others used a control rain at pH 5.6. Lee et al. (1980) applied acid rain three times a week and watered with control rain as needed. This control rain could ameliorate the effects of the acid irrigation. In contrast, Evans et al. (1983) allowed no additional rain on the plots. The differences which cultivars may exhibit is shown by Evans et al. (1983) for soybeans. Shriner and Johnston (1981) showed no difference in yield with the "Lee" cultivar of soybeans or with the red kidney beans but did show a reduced number of nodules in both cases.

Materials and Methods

Location and Soil Type

The study site was located on the south side of Lake McCloud, an ultra-oligotrophic lake in the Ordway Preserve, three miles east of Melrose, Florida. The preserve is property of the University of Florida. The primary soil of the lake watershed and the experimental plots was Candler, a Typic Quartzipsamment. Chemical analysis of this soil is presented in Table 2.

Table 2. Selected Chemical and Physical Characteristics of the Candler Soil (0-15 cm)

Sand	Silt	Clay	Organic Carbon	pH	Exchangeable Cations				H	CEC	Base Saturation
					Ca	Mg	K	Na			
----------%----------					-----cmol (p^+)/kg----------						%
97.0	1.9	1.1	0.73	4.8	0.06	0.027	0.01	0.023	3.32	3.44	3.73

Plot Description

The 1981 field plot design consisted of two transects, each including three 75 m^2 plots. Transects were placed parallel to each other and approximately 30 meters apart projecting perpendicular to the lake. Plots within each transect were 30 meters apart, with the plot nearest the lake approximately 30 meters from the lake edge and above the grass line. Distances between transects and plots within transects were chosen to minimize aerial drift between treatments. In 1982 an additional transect was added. Figure 1 illustrates plots, transects, and lake locations.

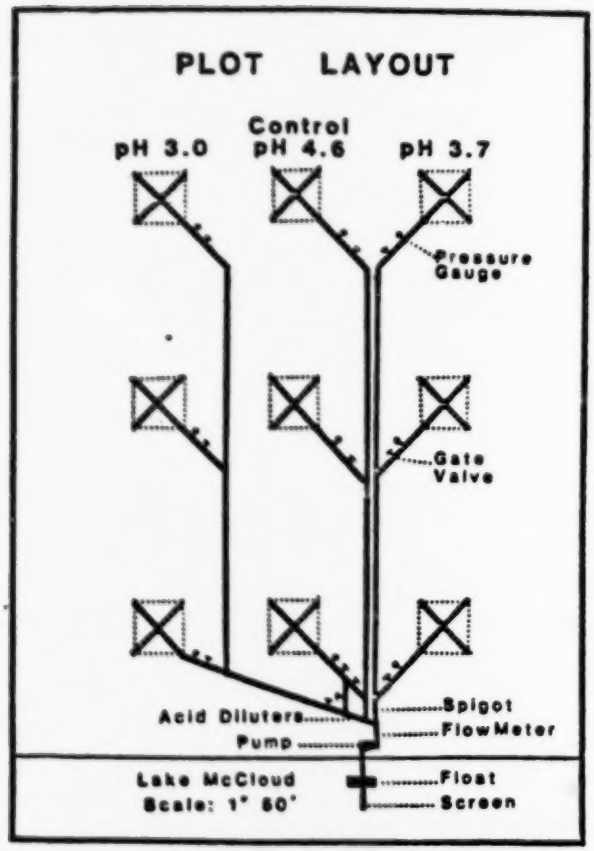

Fig. 1 Field experimental design showing relationship of individual plots and pH treatment transects

Plot Irrigation and Treatments

The first series of irrigations was conducted from March 1981 to July 1981. Fifty cm total of irrigation water was applied in 2.54 cm increments during that period. The irrigation events were evenly spaced. Simulated acid rain treatments consisted of acidified lake water at pH 3.7 and untreated lake water at pH 4.6 (control). Using a liquid chemical injector (Chemilizer Products, Inc., Clearwater, FL) on the transect main irrigation lines, a mixture of 70:30 H_2SO_4:HNO_3 was added to lake water to bring the pH to 3.7. One treatment was applied per transect. Irrigations were made using a 10 h.p. centrifugal pump at 65 psi head pressure and at 40 psi plot pressure. Four impact sprinklers were mounted per plot (one at each corner) with each sprinkler swinging ¼ arc and delivering 7.95 Lpm. Flowmeters, pressure gauges, a conductivity bridge and pH meter were used to monitor water flow and chemistry during irrigation events.

In 1982, the field plot acid rain treatment was modified and a pH 3.0 transect was added consisting of three plots. The second year irrigation events consisted of 18 irrigation applications (approximately 6 cm/irrigation) for a total of 100 cm irrigation from March 1 to August 31, 1982.

Soil Chemistry

Suction tubes with a porous fritted glass disc were placed at 15, 45, and 75 cm depths for the 1981 irrigation. Five tubes were placed at each depth in each plot. The 45 cm depth tubes were eliminated for the 1982 irrigation. Suction was drawn on each tube after each irrigation event and soil solutions were collected and analyzed for conductivity, pH, K, Ca, Mg, NH_4, NO_3, SO_4, P, and Al by appropriate atomic absorption or colorimetric techniques. Soil samples were collected at various depths from the plots and analyzed for pH and extractable cations by neutral normal ammonium acetate.

Results and Discussion

Soil pH's were analyzed at three depths before and after acid rain irrigations for the 1981 and 82 irrigation periods (Table 3). Data are averages of all plots receiving similar treatments. The pH 4.7 (or control) lake water irrigation had no effect on soil pH at any depth, which is not surprising since the untreated soil and lake pH are almost the same. For the pH 3.7 irrigations no soil pH change could be detected below the 7 cm depth. Shallow soil depth samples (0-7 cm) were collected for the 1982 irrigation since it was determined that any change in soil pH would only occur at the very surface of the soil. A decrease of approximately 0.3 pH units occurred for the 0-7 cm depth with the pH 3.7 treatment.

Table 3. Effects of Acid Rain on Soil pH over Two Years

Soil depth (cm)	pH 4.7 Control				pH 3.7 Irrigation				pH 3.0	
	B*		A**		B		A		B	A
	B1	B2	B1	B2	B1	B2	B1	B2	B2	B2
0- 7		4.73		4.77		4.87		4.60	4.83	4.43
0-15	4.73	4.73	5.20	5.00	4.88	4.87	5.13	4.83	4.83	4.63
15-75	4.80	4.53	5.33	4.73	5.30	4.57	5.20	4.63	4.70	4.53

* Before irrigation
** After irrigation

Data is only available for 1982 with the pH 3.0 treatment. Decreases in soil pH after acid rain irrigations were noted at all soil depths with the largest (0.4 units) occurring at the 0-7 cm depth.

Figures 2 and 3 show comparisons of data collected from 1981 and 1982 as well as the effects of acid rain pH on the soil solution Ca and Mg levels. Soil solution samples were collected from the suction tubes after each acid rain irrigation and analyzed. The horizontal axis on the figures of acid rain represents the cumulative amount of irrigation water applied. Each line represents 16 and 17 irrigation events for 1981 and 1982, respectively.

Levels of Ca and Mg found in the soil solution were generally slightly higher in 1981 for the control and pH 3.7 treatments when compared to 1982. This could be due to the fact that higher levels of Ca and Mg were present in the soil initially and the acid leaching in 1981 slightly lowered extractable levels for 1982. Another cause could be that higher natural rainfall occurred in 1982 thus slightly diluting soil solution Ca and Mg levels.

In all cases, the acid irrigation treatments of pH 3.7 and 3.0 increased the concentrations of Ca and Mg in the soil solution sampling tubes over the control irrigations. At the 15 cm sampling depth, the highest levels of Ca and Mg in the solution occurred early in the acid rain irrigations sequence (15-25 cm). The pH 3.0 treatment in 1982 clearly illustrates the rapid increase in Ca or Mg levels in soil solution followed by a gradual decrease in levels with additional irrigations. The rather sudden decrease in Ca or Mg concentrations in the pH 3.0 treatment at the 15 cm depth and at the 25 cm acid rain irrigation level may have been due to a rather heavy natural rain (4 cm) that occurred between irrigations and sampling thus diluting the sample collected.

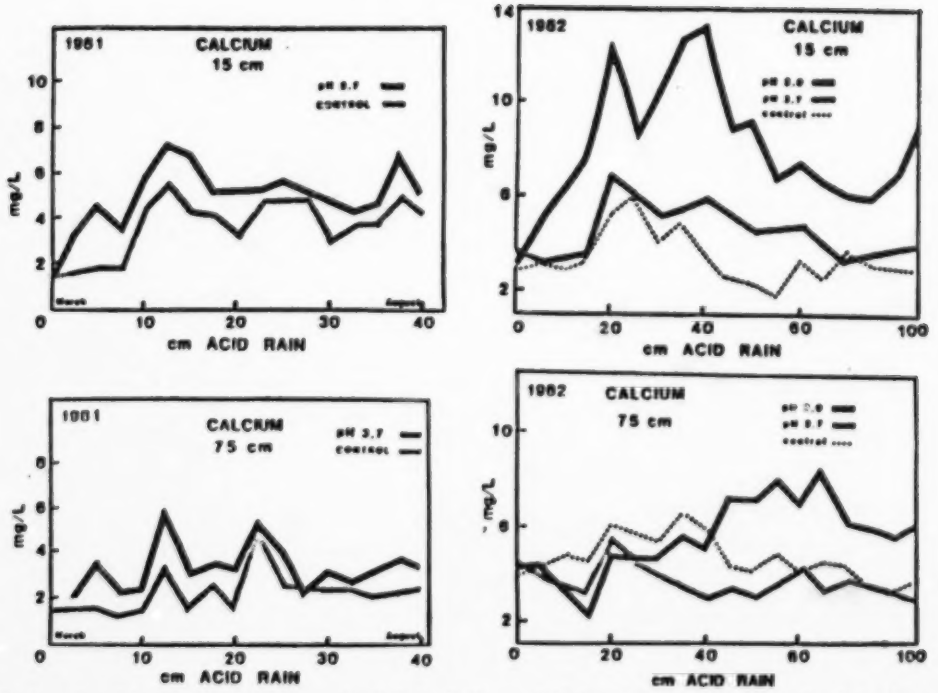

Fig. 2 Effects of acid rain irrigations at pH 3.0, 3.7, or 4.7 (control) on the level of Ca in soil solution samplers at 15 or 75 cm soil depths under field conditions for 1981 and 1982

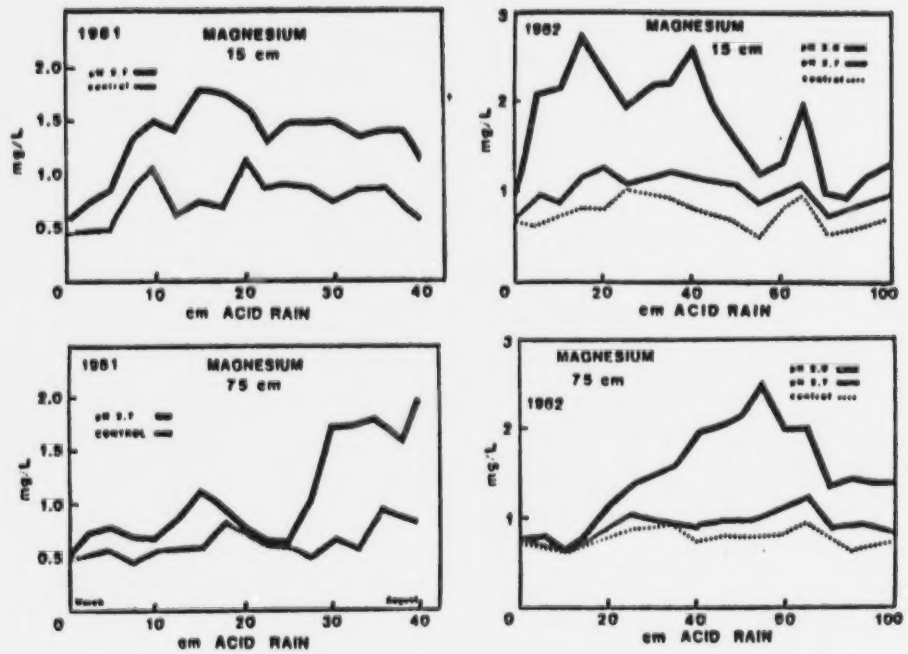

Fig. 3 Effects of acid rain irrigations at pH 3.0, 3.7, or 4.7 (control) on the level of Mg in soil solution samplers at 15 or 75 cm soil depths under field conditions for 1981 and 1982

Soil solution samples collected at 75 cm show a different elution pattern for Ca and Mg compared to the 15 cm depth. The graphs indicate a slow rise in Ca and Mg levels to a maximum level for the pH 3.0 treatment of 8 and 2.5 mg/L, respectively. The 75 cm 1981 graph for Ca does not show the gradual rise, however only 40 cm of acid irrigation were applied to the plots whereas 100 cm of acid irrigation were applied in 1982. At the 40 cm level of acid rain in 1982, the pH 3.0 treatment begins to show a steady increase in Ca concentration in the soil solution followed by a slow decrease.

In contrast to Ca, Mg levels in the pH 3.7 treatment for 1981 began to rise after 25 cm of precipitation and continued to increase. The 1982 data for Mg at 75 cm provides a clearer view of changes in Mg concentration with acid irrigations. For the pH 3.7 treatment a consistently higher but small difference (0.5 mg/L) is noted when compared to control Mg concentrations. The pH 3.0 treatment shows a gradual rise in Mg levels peaking at 2.5 mg/L then gradually decreasing.

It must be noted that 1982 was the first year for acid treatments at the pH 3.0 level whereas for the control and pH 3.7 treatments, it was the second year of irrigation. Since significant quantities of Ca or Mg had already been leached from the pH 3.7 treatments the first year, second year graphs may show substantially smaller differences between the control and pH 3.7 treatments.

In contrast to Ca and Mg, the graphs for K (Figure 4) show that the acid irrigation treatments in 1982 of pH 3.0 and 3.7 do not increase levels of K in the soil solution samplers at 15 or 75 cm compared to the control irrigation. Apparently the control irrigation at pH 4.7 is sufficiently acid to remove K from the exchange complex of the soil. This fact, plus the nature of monovalent K ions, causes lower pH irrigations to have little or no additional effect on K concentration in the soil solution.

Aluminum is an important element when considering toxic or detrimental effects of an element to plant roots and aquatic organisms. More specifically, concentrations of 0.2 to 0.4 mg/L Al^{+3} soil solution could be toxic to plant roots. Figure 5 illustrates Al^{+3} levels in the soil solution samplers at the various acid irrigation treatments. A maximum of 0.2 mg/L Al were found in the pH 3.7 treatment and greater than 5 mg/L were determined in the pH 3.0 irrigation. The Al level in the soil solution was found to be increasing in the pH 3.0 treatment after 100 cm of acid irrigation was applied. The movement pattern for Al at the 15 cm depth was considerably different than for other elements at this depth. Very little difference in Al levels for the different acid irrigations was noted until approximately 40 cm of acid rain had been applied. At this point the pH 3.0 treatment showed a rapid rise in Al levels. The rapid rise in Al levels in the soil solution with the pH 3.0 treatment can probably be explained by examining the change in pH of the soil solutions collected (Figure 6). At the 40 cm acid rain level the pH of the soil solution for the pH 3.0 treatment rapidly falls to below 5.0 and remains approximately level. At pH's below 5, Al becomes much more mobile

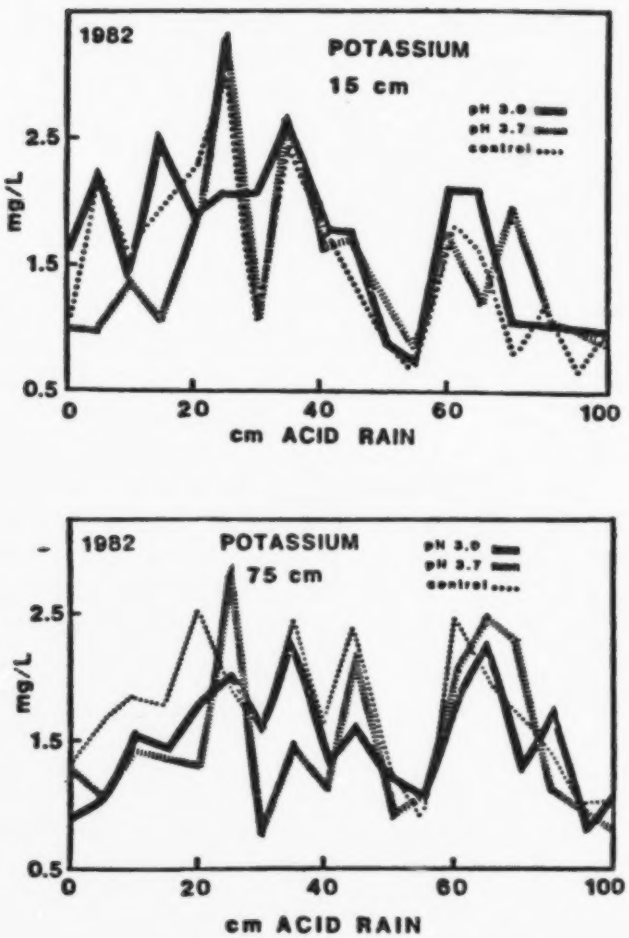

Fig. 4 Effects of acid rain irrigations at pH 3.0, 3.7, or 4.7 (control) on the level of K in soil solution samplers at 15 or 75 cm soil depths under field conditions

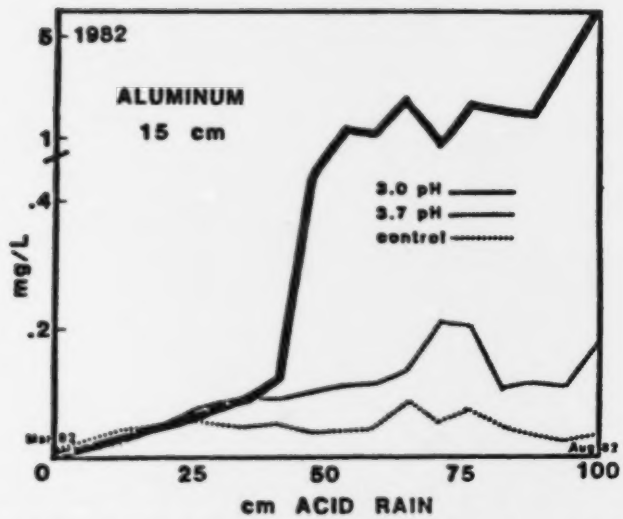

Fig. 5 Effects of acid rain irrigations at pH 3.0, 3.7, or 4.7 (control) on the level of Al in soil solution samplers at 15 or 75 cm soil depths under field conditions

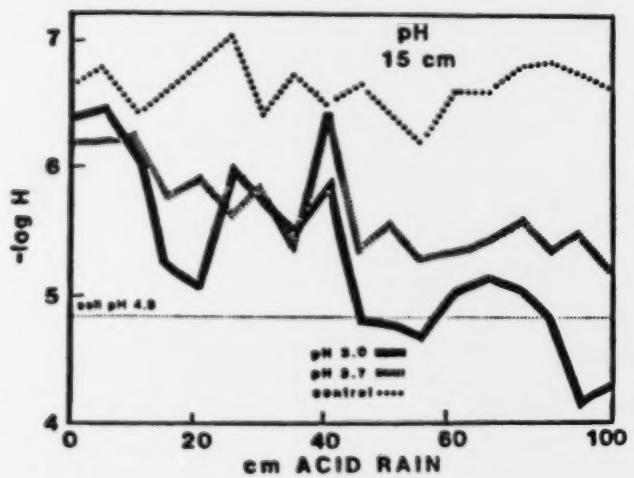

Fig. 6 Effects of acid rain irrigations at pH 3.0, 3.7, or 4.7 (control) on pH levels in soil solution samplers at 15 or 75 cm soil depths under field conditions

in the soil and can be removed from the exchange complex. This exchangeable Al is apparently causing the much higher levels of Al shown in Figure 5 with the pH 3.0 treatment. The further decline in solution pH (close to 4.0) for the 3.0 treatment at the 90-100 cm in acid rain level (Figure 6) corresponds with another increase in Al^{+3} in the soil solution at the same irrigation pH and cm of acid rain.

Effects of acid rain irrigations on changes in soil solution pH (Figure 6) show the control remains approximately constant at pH 6.7 over the entire 100 cm irrigation. The pH 3.7 irrigation treatment shows a slow decline from pH 6.2 to 5.2 of the soil solution over the entire period of application of acid rain. For the pH 3.0 irrigation treatment soil solution pH declines more steeply and falls from 6.4 to 4.3. If additional acid rain at pH 3.7 were to be added to these plots, it is anticipated that a sharp rise in Al levels in the soil solution would occur when the soil solution pH declined to values less than 5.

The major anion measured in the soil solution tubes for the field irrigation treatments was SO_4 (Figure 7). Sulfate was the major anion in the natural rain and was added in the sulfuric:nitric acid simulated acid rain treatments. Thus the magnitude of SO_4 concentration in the soil and its movement or possible adsorption could have an important effect on the movement of the cations.

Figure 7 shows the movement of SO_4 during the irrigation period at two depths. Sulfate at the 15 cm depth increased rapidly from the level added in the lake water and by the 40 cm application was slightly above the input concentration of 41 mg/L for the pH 3.0 treatment. There was then a sharp decline and the SO_4 stabilized in soil solution at approximately 25 mg/L. This decrease in part could be explained by three heavy rain events during this time in the irrigation sequence.

Sulfate in the soil solution for the pH 3.7 and control treatments approached the input concentrations of 14 and 7 mg/L, respectively. Note that the dotted horizontal lines (Figure 7) are the input irrigation SO_4 concentrations for pH 3.0, pH 3.7 and control (lake pH 4.7), and are 41, 14 and 7 mg/L, respectively.

Sulfate at the 75 cm depth for the pH 3.0 treatment initially remained lower until 40 cm of irrigation where there occurred a sharp rise to 25 mg/L. Although the SO_4 concentration at 75 cm depth never reached the input concentration of 41 mg/L, it did follow a similar pattern as SO_4 at the 15 cm depth. The pH 3.7 treatment also never reached the input concentration of 14 mg/L.

These results indicate that SO_4 at low levels is relatively mobile in the upper 15 cm of this sandy soil. There is obviously a capacity for some initial adsorption. At the 75 cm depth, approximately 65% of the total added SO_4 at the higher concentration (41 mg/L) was adsorbed by the soil above this depth, with lesser relative adsorption at the lower SO_4 concentrations (14 and 7 mg/L) being 40 and 38%, respectively.

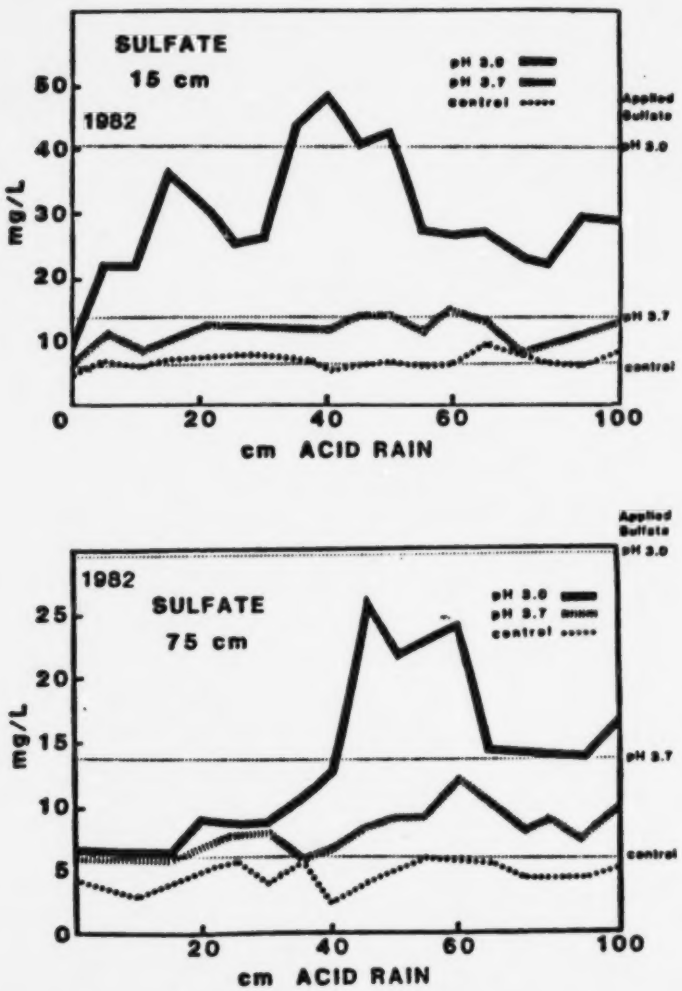

Fig. 7 Effects of acid rain irrigations at pH 3.0, 3.7, or 4.7 (control) on the level of SO_4 in soil solution samplers at 15 or 75 cm soil depths under field conditions

It is not unreasonable to project that a higher percentage of the SO_4 would be adsorbed at even greater depths. Thus movement of cations could be impeded by the SO_4 adsorption mechanism, since SO_4 could act as a bridging mechanism in cation retention, even in soils of low clay and organic matter content.

Research Needs in Florida

It is anticipated that acid deposition or acid rain problems will increase in Florida over the next decade. Direct effects on soil chemical changes including increased leaching of plant nutrients and movement of Al in the soil solution need considerably more research in field and laboratory studies. Effects of acid deposition on different types of soils under different vegetation needs more research. Initial studies have indicated that potential problems exist with increases in acid deposition but the magnitude of the problem can not yet be quantified.

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